IMAGE Low Energy Neutral Atom (LENA) Instrument Thermal Balance Test Report

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SUMMARY

A thermal balance test was performed on the IMAGE Low Energy Neutral Atom (LENA) instrument main box from January 6-8, 1999. Prior to the thermal balance test, a bakeout of was performed at 70◦C. Due to the schedule constraint, the thermal balance test was limited to a hot thermal balance only. The Thermal Mathematical Model (TMM) predicted temperatures have good agreement with the thermal balance test results. All the TMM predictions are within 3◦C of the test results. A majority of the TMM predicted temperatures are within 2◦C of the test results. Adjusting the flight worst hot and cold operating temperature predictions by incorporating the differences between the TMM predictions and test results still provides temperatures with acceptable margin. The good agreement between the temperature predictions and the test results indicates that no modifications in the LENA main box TMM and thermal design are needed. It also ensures that the LENA main box thermal design will satisfy all temperature requirements in the flight environments. Dry mount for the C&DH caused a 13-15◦C temperature gradient between the C&DH housing and cold plate. Wet mount using RTV thermal conductive filler is recommended to increase the mounting interface thermal conductance.

1.0 INTRODUCTION

The Low Energy Neutral Atom (LENA) instrument has been developed by NASA Goddard Space Flight Center (GSFC) Code 692 in collaboration with the University of Maryland, and Lockheed Martin. It is intended for use on the IMAGE spacecraft being built by Lockheed Martin for Southwest Research Institute. The spacecraft is scheduled to launch in January 2000.

The LENA thermal balance test program was performed by GSFC to: (a) validate the LENA main box thermal model; (b) ensure that the LENA main box thermal design satisfies the temperature requirements in the flight environments.

2.0 TEST ITEMS

The thermal balance test was performed in Chamber #241 of the Simulation and Testing Facility at GSFC. The test items include the following flight units: LENA main box; and C&DH. The units were mounted on two different cold plates as illustrated in Figure 1. Due to the schedule problem in the Thermal Coatings Laboratory, it was unable to complete the vacuum deposition of the conductive composite coating on the collimator nosepiece in time for the thermal balance test. Therefore, 1-mil aluminized kapton was taped to the exterior of the nosepiece for the thermal balance test. It is acceptable because emittance is the only thermo-optical property required in the thermal balance test, and the emittance of 1-mil aluminized kapton is close to that of the conductive composite coating (0.63 versus 0.68).

3.0 INSTRUMENTATION

There were twenty-two (22) copper-constantan thermocouples taped to the LENA external surfaces in the thermal vacuum test: twenty on the LENA main box, and two on the C&DH. Also, three were taped to the exterior of the doghouse, two were taped to each cold plate, and one was taped to the scavenger plate. The doghouse was used to simulate the spacecraft interior temperature. The scavenger plate, when flooded with LN_2, helped maintain the chamber pressure at 2×10^{-6} torr.

4.0 PRE-TEST THERMAL ANALYSIS

Thermal analysis of the thermal balance test was performed prior to the test. Figures 2 and 3 present the transient cooldown of the LENA main box following the 70°C bakeout. It was assumed the chamber shroud, cold plate and doghouse temperatures were set the thermal balance boundary temperatures immediately after the bakeout. It would require nearly two days to reach thermal stabilization. To reduce the test time, a plan was established to increase the temperature transition rate by setting the chamber shroud, cold plate and doghouse temperatures to much colder than the thermal balance boundary temperatures initially. It was also planned that when the LENA temperatures drop below 20°C, then the chamber shroud, cold plate and doghouse temperatures are set to the thermal balance boundary temperatures.

5.0 TEST PROCEDURE

The planned procedure was followed. The chamber pressure was at 1.8 x 10^{-6} torr throughout the thermal balance test. The LENA instrument was in the "V/10" power mode in the thermal balance test. Figure 4 shows the thermal balance test profile.

The test procedure is summarized as follows:

1. When the vacuum chamber pressure reached 1 x 10^{-5} torr, the temperatures of the cold plates, and the temperature controllers of the test heaters on the LENA main box and doghouse were set to 70◦C or warmer. The vacuum chamber shroud wall temperature was increased to 65◦C gradually so that it was always cooler the LENA instrument by 5◦C. The temperatures of the cold plates, and the temperature controllers of the test heaters on the LENA main box were adjusted to maintain the temperature rates of change of LENA at no more than 35◦C/hr, and to ensure that LENA did not exceed 70◦C.

2. Eleven hours later, the LENA instrument temperature reached 70◦C.

3. Four hours later, the bakeout was ended, and transition to the hot thermal balance temperatures began. The temperatures of the cold plates, vacuum chamber shroud walls, and doghouse were decreased to maximize the rate of temperature change, which was also maintained at or below 35◦C/hr. The chamber shroud was maintained at least 5◦C colder than LENA.

4. After ten hours, the LENA main box reached 20◦C. The temperatures of the cold plates, vacuum chamber shroud walls, and doghouse were set to the thermal balance set points. The LENA was turned on and was maintained at the "V/10" power mode. All the LENA main box thermocouple temperatures were allowed to reach thermal stabilization -- defined as having occurred when no temperature sensor exceeded a change of 0.1^{o}C for a two-hour period for six consecutive hours with a decreasing slope (temperature change per unit time) over the six-hour period.

5. Eleven hours later, thermal stabilization was achieved.

6. Following the hot thermal balance, the LENA instrument was turned off. The temperatures of the cold plates, vacuum chamber shroud walls, and doghouse were increased to warm LENA to 30◦C. The chamber wall temperature was raised to 22◦C gradually.

7. When all the LENA thermocouples were within 2∘C of 30∘C, and the chamber shroud was within 2∘C of 22∘C, backfill of the chamber to 600 torr began. Backfill was completed in one hour.

5.0 ANOMALIES

There was no failure in the test. There was an anomaly in conjunction with with the flight cable which connected the LENA main box to the C&DH. There was also an anomaly related to the flight software.

6.0 TEST RESULTS

6.1 Boundary Conditions

The temperatures of cold plate #1, the doghouse and the chamber shroud wall are recorded in Table 6-1. LENA was in the "V/10" mode after it was turned on in the thermal balance test. The voltage and current measured were 30 V and 0.48 A, respectively. The measured power dissipation in the "V/10" mode is presented in Table 6-2.

Table 6-1. Thermal Balance Boundary Temperatures from Test Facility (∘C).

Cold Plate #1	28.8
Doghouse	28.2
Chamber Shroud Walls	-60

Table 6-2. Power Dissipation in Thermal Balance Test (W).

	V/10 Mode
Optics P/S	.15
Collimator P/S #1	.15
Collimator P/S #2	.15
MCP P/S #1	.15
MCP P/S #2	.15
TOF Electronics	1.6
C&DH	12

6.2 LENA Main Box Temperatures

The LENA main box temperatures at thermal stabilization of the hot thermal balance test are presented in Table 6-3. Appendix A presents the temperature plots obtained during the test.

6.3 Correlation With T/B Test Predicted Temperatures

Prior to the thermal balance test, the LENA main box thermal math model (TMM) was modified for the test configuration. This included the vacuum chamber shroud, test doghouse, and cold plate.

For components with one node in the TMM but more than one thermocouple, an average temperature was obtained. For components with more than one node but only one thermocouple, the test data was compared with the predicted temperature of the node closest to the thermocouple. Table 6-3 also shows a list of thermocouples and their locations. Table 6-4 presents the definition of nodes in the SINDA model of the TMM and the corresponding thermocouple number(s).

The LENA main box TMM was re-run using the exact boundary conditions obtained during the test. A comparison was then made between the test results and the TMM predictions according to the methodology described above.

The TMM predicted temperatures have good agreement with the thermal balance test results. This is shown in Table 6-5. All the TMM temperature predictions are within 3◦C of the test results. A majority of the TMM temperature predictions are within 2◦C of the test results. The good agreement between the predictions and the test results indicate that no modifications in the LENA main box TMM or thermal design are needed.

Table 6-6 presents the flight flight worst hot and cold case temperature predictions in the operating mode. They have been adjusted by incorporatedting the differences between the TMM predictions and test results. A beginning-of-life solar absorptance of 0.08, for the conductive composite coating, was used in the worst cold case. It was assumed to degrade to 0.2 in the worst hot case at the end-of-life. In the non-operating mode, the survival heaters prevent the LENA main box from falling below –40◦C. Therefore, the LENA main box thermal design will satisfy all the temperature requirements in the flight environments. In the operating mode, the power dissiaption of the full operational mode was used. Table 6-7 shows the power dissipation.

The thermal balance test was intended for the LENA main box. The test data also revealed that dry mount for the C&DH caused a 12-15◦C temperature gradient between the C&DH housing and cold plate. Using a 12 W power dissipation measured, the interface conductance is therefore less than 1 W/◦C. Wet mount using a RTV thermal conductive filler will increase the interface conductance and reduce the temperature of the C&DH significantly.

6-3. List of LENA Thermal Balance Test Thermocouples and Temperatures at Thermal Stabilization.

Thermocouple #	Location	Temperature (∘C)
1	Cold Plate #1	28.8
2	Cold Plate #1	28.8
3	Cold Plate #2	32.6
4	Cold Plate #2	32.4
5	Microchannel Plate Power Supply #1	8.9
6	Microchannel Plate Power Supply #2	10.3
7	Collimator Power Supply #1	6.2
8	Collimator Power Supply #2	5.9
9	Optics Power Supply	9.6
10	Time of Filght Electronics	11.6
12	LENA Main Box Left	9.8
13	LENA Main Box Right	10.9
14	LENA Main Box Top	5.2
15	LENA Main Box Back	9.8
16	C&DH Housing Right	45.4
17	LENA Collimator Nosepiece	2.1
19	Microchannel Plate Power Supply #1	9.0
20	Microchannel Plate Power Supply #2	10.5
21	Collimator Power Supply #1	6.5
22	Collimator Power Supply #2	6.0
23	Optics Power Supply Near Feet	9.5
24	Time of Filght Electronics	11.6
25	LENA Collimator Nosepiece	1.3

Thermocouple #	Location	Temperature (∘C)
26	LENA Main Box Housing Top	5.1

Table 6-3 Continued

Thermocouple #	Location	Temperature (∘C)
27	LENA Main Box Housing Back	9.2
29	Doghouse Right	28.0
30	Doghouse Top	28.3
31	C&DH Housing Right	48.1
32	Doghouse Left	26.9
27	LENA Main Box Housing Back	9.2
29	Doghouse Right	28.0
30	Doghouse Top	28.3
31	C&DH Housing Right	48.1
32	Doghouse Left	26.9

Table 6-4. LENA Main Box TMM Nodal Definition and Corresponding Thermocouple Number(s).

Node #	Thermocouple #	Definition
1000	5, 19	Microchannel Plate Power Supply #1
1100	6, 20	Microchannel Plate Power Supply #2
1400	7, 21	Collimator Power Supply #1
1500	8, 22	Collimator Power Supply #2
900	9, 23	Optics Power Supply
1300	10, 24	Time of Filght Electronics
7908	12	LENA Main Box Left
7919	13	LENA Main Box Right
7923	14	LENA Main Box Top
7912	15	LENA Main Box Back
300	17	LENA Collimator Nosepiece Left
400	25	LENA Collimator Nosepiece Right
7921	26	LENA Main Box Housing Top
7913	27	LENA Main Box Housing Back

Table 6-5. LENA Main Box Hot Thermal Balance Test Results Versus TMM Predictions (^oC) (See Table 6-4 for Definition of Nodes).

TMM Node #	Corresponding Thermocouple # or Average of Thermocouple #s	Test Result	Prediction	Δ (Prediction - Test Result)
1000	5, 19	9.0	7.8	-1.2
1100	6, 20	10.4	8.4	-2.0
1400	7, 21	6.3	6.4	0.1
1500	8, 22	5.9	5.9	0.0
900	9, 23	9.5	8.8	-0.7
1300	10, 24	11.6	11.4	-0.2
7908	12	9.8	7.5	-2.3
7919	13	10.9	8.3	-2.6
7923	14	5.2	6.1	0.9
7912	15	9.8	8.5	-1.4
300	17	2.1	1.3	-0.8
400	25	1.3	3.0	1.7
7921	26	5.1	7.0	1.9
7913	27	9.2	8.4	-0.8

Table 6-6. LENA Main Box Flight Temperature Predictions in Operating Mode (◦C).

Node #	Definition	Worst Hot Operating	Worst Cold Operating
1000	Microchannel Plate Power Supply #1	9.2	-28.0
1100	Microchannel Plate Power Supply #2	10.7	-26.7
1400	Collimator Power Supply #1	6.0	-30.5
1500	Collimator Power Supply #2	5.1	-31.7
900	Optics Power Supply	10.0	-27.9
1300	Time of Filght Electronics	9.9	-27.6
7908	LENA Main Box Left	8.6	-29.0
7919	LENA Main Box Right	10.0	-27.4
7923	LENA Main Box Top	6.3	-32.2
7912	LENA Main Box Back	11.1	-27.4
300	LENA Collimator Nosepiece Left	-0.1	-37.0
400	LENA Collimator Nosepiece Right	-0.9	-33.1
7921	LENA Main Box Housing Top	6.2	-28.8
7913	LENA Main Box Housing Back	10.4	-29.1

Table 6-7. Power Dissipation in Full-Operational Mode in Flight (W).

	Full-Up Operational Mode
Optics P/S	.72
Collimator P/S #1	.45
Collimator P/S #2	.42
MCP P/S #1	.36
MCP P/S #2	.36
TOF Electronics	1.2
C&DH	12

APPENDIX A. Test Temperature Plots (See Attached).